Chapter 7
Novel Technology for Learning in Medicine

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Abstract In this chapter we will present some medical educational approaches together with their links to different learning objectives and learning situations. We will also present various forms of computer-based technology, which aim to enhance the teaching and learning capabilities of doctors, mostly in the form of 3D visualisation, simulation and haptic technology. We will focus on research conducted in the areas of spinal anaesthesia, surgery and emergency. Finally, we will emphasise some challenges of our domain which are related to the interaction between medical education, technological and computer factors.

Keywords Technology-enhanced learning · Simulation · Medical education · spinal anaesthesia · Surgery and emergency

7.1 Introduction

The nature of postgraduate medical training in Europe is changing greatly. The main determinants of this change are the European Working Time Directive (fewer teaching and learning hours available), the increase in transnational mobility of doctors (trainees and independent practitioners), altered patient expectations, the Bologna Accord and new forms of governance of training and practice. The implication of these changes is that doctors have a reduction in training opportunities. Traditionally medical education was based on an experience-based model (apprenticeship), where junior doctors and medical students learn the procedures on real patients (thereby exposing patients to inexperienced practitioners). As this training procedure becomes less and less acceptable or appropriate, young doctors will acquire less "hands-on" training during everyday work situations, in particular in psychomotor skills.

With respect to medical skills, the aim is for trainees to practice skills in a safe environment, before refining them in the real world. These "paradigm shifts" in

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medical education, where the focus is on expertise rather than experience (Aggarwal & Darzi, 2006), require new tools, educational theories, teaching techniques and curricula. Different types of technology-enriched learning environments are presented in this chapter as examples of innovative instructional approaches that can speak to these training needs. Technology-enhanced learning (TEL) provides a safe, standardised way to practice complex skills (Lajoie & Azevedo, 2006).

The educational approaches for medical education that are presented in this chapter explicitly take into account the different learning objects and pedagogical settings that are at stake. Moreover, this chapter also presents various forms of computer-based technology which aim to enhance the teaching and learning capabilities of doctors, mostly in the form of 3D visualisation, simulation and haptic technology. We will focus on research conducted in the areas of spinal anaesthesia, surgery and emergency.

Finally, we will challenge the relationship between medical education, technological and computer factors.

7.2 General Framework of the Presented Studies

A largely accepted model of the development of expertise considers that expertise emerges through the concomitant development of a cognitive model and an operative model of the activity (see, for example, Samurçay, 1995). Theory is necessary to practice, and practicing allows the reorganisation and operationalisation of theory. The more the subject has been confronted with a variety of situations, the more efficient he is, which means that he can easily adapt his action to a new situation. In this context the appeal of TEL environments is obviously in allowing the learner to be confronted with situations he could not have met, or dealt with, in real settings. Particularly in hospitals, and for evident reasons, learners are never left "alone" to solve a problematic situation. Taking a constructivist point of view which assumes a personal construction of knowledge through interaction with a situation, we aim to design environments that will complement the traditional model of learning in medicine.

In this context, this text will describe different TEL environments involved in problem-based and problem-solving situations. These situations are either integrated in the "operating under supervision" phase or constitute an additional phase, aiming at enhancing the articulation between theory and practice (Vadcard & Luengo, 2005). The related technologies constitute a very important and relevant category of TEL environment for medical training, that is, simulations. Within this wide category we will distinguish different kinds of simulators according to their technological characteristics and accuracy (Romero, Ventura, Gibaja, Hervás, & Romero, 2006):

- *Screen-based simulators* are the most classic type; typically the user indicates the sequence of action using the presented interface and the system shows the state result of this manipulation. It can provide customised feedback. If this kind of simulator is executed remotely over the Internet it is called a Web-based simulator.

- *Virtual reality* is a technology allowing a user to interact with computer-generated space and objects which are presented in a three-dimensional format and sometimes with sensory information (sound, tactile, etc.). Uses range from anatomy instruction to surgery simulation (particularly in laparoscopy). Utilisation of virtual reality in the medical fields is thought to incorporate the latest research.
- *Training devices and part-task trainers* are of intermediate fidelity and allow users to acquire the skills for a specific task prior to patient contact.
- *Realistic simulators* are realistic human simulators, including an organ or a life-mannequin which simulates a real patient. Special sensors allow detection of the face mask and tracheal tube. Several pre-programmed events, including patient bucking, cardiac arrest and changes in blood pressure, can be activated.

In the next sections we develop some examples of learning situations using these kinds of TEL environments, developed by Kaleidoscope Network of Excellence teams.

7.3 Operating Under Expert Supervision: The Case of New Training Devices

In Europe, learning to be a surgeon is a 13-year-long process. The seven final years are dedicated to practical education. In most European hospitals, every operation is performed by both a surgeon and a resident. The latter is given increasing responsibilities during the operation, under the supervision of the expert, according to his/her degree of acquired expertise. This is the “professional hands-on training” phase. This phase has proven its efficiency in the training process, particularly in the development of practical skills and procedural knowledge. However, it has some limitations.

The fact that professional hands-on training is not safe for the patient is one classically described aspect. Let us also point out some other aspects which are more related to an epistemic point of view of this training process.

First of all, it is important to note that the surgeon must assume two roles during real operations. He must be both the expert, thus performing the operation well, and the teacher, providing the resident with the essentials that allow him to understand the whole activity (actions performed, controls required, organisational constraints, etc.). But, as it is now well known, experts know much more than they can express (Schön 1983) Empirical knowledge, built during their years of practice, is encapsulated in the action and cannot be verbalised by the expert. This means that part of the knowledge at play during the operation cannot be grasped by the resident.

Another important aspect of professional hands-on training is that the surgeon is first an expert. This means that he will take charge of the operation as soon as he considers that the resident is not able to perform it correctly. In educational terms this means that the resident often cannot solve a problem by himself/herself.

The surgeon shows him the solution. This last point illustrates the perspective that technology-enhanced learning can offer to complete professional hands-on training with problem-solving environments. Added to the fact that residents' training is refined by the cases on which they assist during these 7 years, the further value of TEL for medical education becomes evident.

Some other aspects of learning/operating under expert supervision might include the nature of the trainer (expert)/trainee interaction (relationship) as an important determinant of learning procedural skills (we will develop here an example based on some original data related to using a procedure).

Important aspects of this relationship include the physical location of each relative to the other, perceived conflict between service delivery and education, multiple roles for trainer/expert and trainee (e.g. for the expert: custodian of patient safety, teacher, future decision-maker regarding trainee's career, health service provider), implicit and explicit expectations and definition of roles within a formal structured training programme.

The transition from the "command performance" (i.e. under expert supervision) to independent practice is also a specific aspect of professional hands-on training. For procedural skills, some evidence exists that proficiency demonstrated in a simulated setting can be reliably translated into performance in a clinical setting (Gallagher & Satava, 2002). The implication is that the value of "expert supervision" can be captured in the form of a very detailed curriculum and results in clinical error rates which are lower than those associated with clinical apprenticeship training.

7.3.1 A Case Study Analysis of Usage of Training Devices for Minimally Invasive Surgery

Minimally invasive surgery presents new obstacles for surgeons attempting to acquire laparoscopic skills. This surgical technique is performed with the help of a camera and long instruments introduced through small incisions into the body. Laparoscopic surgery brings a lot of advantages, particularly for the patient (very small incisions, smaller risks of infections, etc.). For all these reasons, minimally invasive techniques are now ubiquitous and indispensable in the management of surgical disease. However, despite the clinical benefits, significant challenges have been noted: the view of the surgical site is indirect and restricted, the surgeon must observe and manipulate tissues and organs through very small incisions with long and rigid instruments, tactile perception is lost, the feedback of the action is principally visual with a 2D image and finally, the degree of freedom for the instruments' movements (DOF) is restricted at 4. All of these drawbacks are responsible for the long learning curve observed in the training of residents (Forbes, DeRose, Kribs, & Harris, 2004; Sidhu et al., 2004). A new robotic system has been designed in order to suppress the main drawbacks of classical laparoscopy: it permits 3D visualisation of the operative field and the DOF lost in classical laparoscopy.

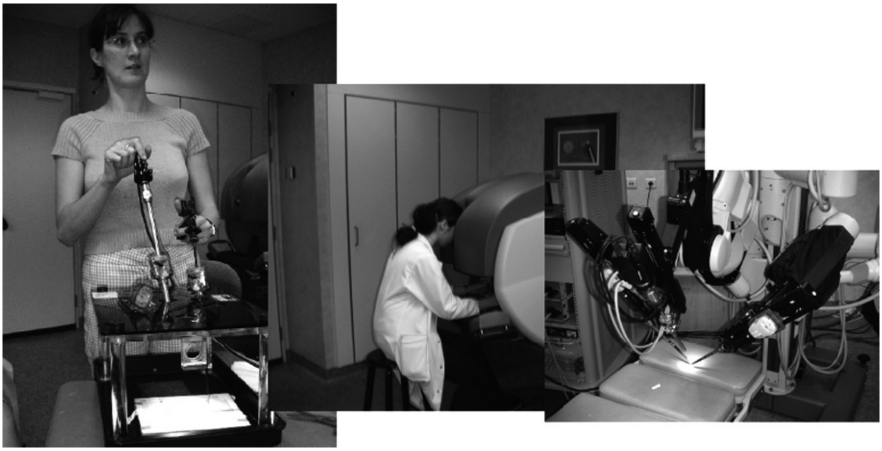

Fig. 7.1 Example of training devices in classical laparoscopy (photo on the *left*) and with the robotic system (*centre* and *right* photos)

In this context of new technology introduction, the University of Liège evaluated the training of medical students and residents in these two techniques (classical and robotic laparoscopy) using bench model inanimate trainers (see Fig. 7.1). Bench model tasks consisted of a "pick and place" task, checkerboard, rings route, circular pattern cutting and suture and knot. All of these tasks were validated by previous studies. We measured speed and accuracy for each task and we asked subjects to answer a questionnaire on their subjective impressions about their performance (satisfaction, self-confidence and difficulty). Data showed that training with these two techniques improved the performance and gesture accuracy of participants differently (Blavier, Gaudissart, Cadière, & Nyssen, 2007). Classical laparoscopy that is performed with a 2D view and low dexterity required more practice than the robotic system that is more intuitive in the view mode and gestures. A 2D view is less natural and requires more controlled cognitive processes and thus entails specific training in order to act in a 2D world (as shown in cognitive psychology, Marotta & Goodale, 1998). Furthermore, training with one technique did not lead to mastery of the other technique: the transfer of skills from one technique to the other was very difficult (Blavier, Gaudissart, Cadière, & Nyssen, 2007). In conclusion, training with both techniques out of the operating room must be differentiated and the training must be more intensive in classical laparoscopy.

Furthermore, these studies showed that using bench models allows us to understand better the nature of the cognitive and motor processes involved in the execution and control of laparoscopic gestures (Blavier, Gaudissart, Cadière, & Nyssen, 2007). This allows us to improve the quality of the training devices. Moreover, if bench models improve surgical performance out of the operating room, several studies have also shown that the skills acquired on bench models transfer to the operating room (Hamilton et al., 2002). In contrast to animals or cadavers, the principal advantages of bench models are their low cost and the possibility of repeating the same task several times at any time and thus evaluating the training or assessing a performance (Gallagher & Satava, 2002; Stone & McCloy, 2004). Finally, studies show a benefit of the training in the improvement of performance but also in the feelings of mastery, familiarity, satisfaction, self-confidence and facility, which are essential factors of well-being, motivation, accurate performance and new technology acceptance in the operating room (Blavier, Gaudissart, Cadière, & Nyssen, 2007; Hamilton et al., 2002; Issenberg et al., 1999). Based on all of these characteristics, most studies encourage the use of bench models in parallel to traditional learning in the training of surgical skills.

7.3.2 Using Haptic Technology to Enhance Spinal Anaesthesia Training

Performance of spinal anaesthesia comprises cognitive knowledge, psychomotor, social and affective skills (judgements, confidence, etc.). Typically, cognitive knowledge of anatomy and pharmacology is achieved before fine psychomotor skills (procedural knowledge) of needle insertion are practiced in the operating room. Medical trainees are currently taught this technique using an apprenticeship approach, that is, watching an experienced anaesthetist and subsequently performing the procedure under supervision.

There is a concerted effort to improve medical training through the use of state-of-the-art technology. However, an aspect that has been overlooked in the design of this technology is the fine psychomotor dimension of learning. As a collaborative effort, the Department of Anaesthesia at Cork University Hospital and Interaction Design Centre, University of Limerick, investigated the feasibility of designing novel learning technology to assist the training of hospital doctors in performing a spinal anaesthesia (DBMT).[1] The team consists of a multidisciplinary group of researchers: medical doctors, system developers and a psychologist. All researchers were involved in all the phases of the design process, however, to a greater or lesser extent. The case studies that were conducted in order to identify key determinants of learning and teaching a spinal gesture were designed and conducted by the medical experts with methodological support from the psychologist. The system developers designed and re-designed the haptic device in close collaboration with the medical doctors and the psychologist. The testing of the final prototype was conducted in Cork University Hospital with all parties involved.

The case studies involved 66 subjects including patients, anaesthetists-in-training, consultant anaesthetists, surgeons and nurses. The results identified a variety of different determinants, including affective factors such as “time or schedule pressure” and “interpersonal dynamics of trainer and trainee” and cognitive factors such as background knowledge (Kulcsár, Aboulafia, Hall, Sabova, & Shorten, 2008).

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[1] The project, named Design-Based Medical Training (DBMT), was funded by the Health Service Executive, Ireland, 2006 (http://www.dbmt.eu/).

The first prototype development of the simulator focused on the psychomotor skill of haptic perception. The identification of the correct placement of a spinal needle was argued to be the most difficult task to perform and also to explain to trainees. The doctor must place a needle in the thin layer of fluid that surrounds the spinal cord. As there are no visual clues, the doctor "feels" the resistive forces as the needle passes through the different layers (skin, subcutaneous tissue and ligaments). Verbal explanation of these sensations to trainees is obviously very difficult, and as mentioned by trainers, recognition and identification of the different (haptic) sensations can only be learned through experience, although the importance of having a mental representation of the anatomy and the procedure was also emphasised.

Among many contributions to understanding mechanisms of senses, Weber at the University of Leipzig (1818–1871) made important discoveries concerning the sense of touch in skill development (Ross & Murray, 1996). He argued that touch becomes more sensitive with practice. Since Weber, haptic perception has received much less scientific attention than vision and hearing.

Derived from the case studies, and supported by Weber, we hypothesised that, through practice, doctors learn the haptic sensation of each layer of tissue and consequently are able to recognise the correct location for injection of anaesthesia.

7.3.2.1 Prototype Development and Initial Evaluation

Before attempting to construct a simulator, a trial was proposed to test the above hypothesis using virtual reality technology and a PHANTOM haptic device (from Sensable Technologies Inc.), which supplies mechanical force feedback to the user. Based on a single expert anaesthetist, a model was proposed with a parameter space of simulated tissue sensations. A comparative study involving 25 anaesthetists (experts and novices) was later conducted, which indicated that expert anaesthetists are able to recognise the "correct" haptic or force feedback for each layer of tissue, although it was not clear if they also have acquired a more "sensitive touch" as suggested by Weber. The study did however provide the basis for developing a simulator that is able to capture the haptic sensations involved in spinal anaesthesia.

The interface is a model of a spine and includes visual feedback. Figure 7.2 shows the setup of the system that is being tested by an anaesthetist using 3D glasses. A spinal needle was attached to the PHANTOM's mechanical arm in order to create a more realistic "hands-on" sensation.

The spine can be rotated, which enables the user to see where the needle has been inserted. From a training point of view this feature was important. Next to being able to "feel" the way though the different layers, visualising the process was also identified by trainees and trainers as critical to learning this technique.

A number of evaluations of the simulator have been conducted with expert and novice anaesthetists. The results are promising, as the haptic sensations were perceived as very similar to those encountered during the real procedure. However,

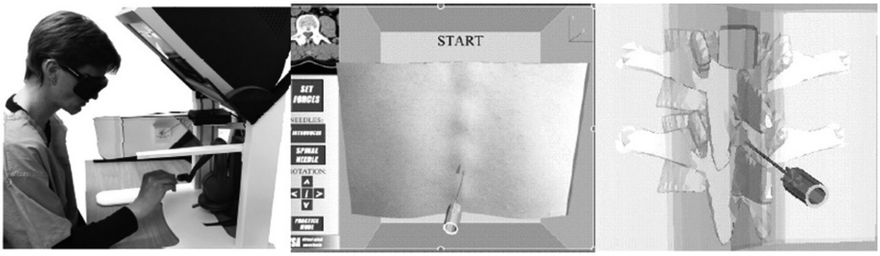

Fig. 7.2 The haptic device setup and screen shots of the interface

besides an accurate simulation of psychomotor procedures such as haptic sensations, a successful training tool will require curriculum, functionality that allows rehearsal and practice, links to educational information and testing capabilities (Shaffer et al., 2001). The development and design of such a complete training tool for spinal anaesthesia, including a valid and reliable competence assessment procedure for cognitive, affective and psychomotor skills of medical trainees, is currently ongoing.[2]

7.4 Problem-Based Learning and Simulation of Clinical Material

In problem-based learning (PBL), problems are used as a focus for integrated learning of basic science and clinical knowledge along with clinical reasoning skills. In short, the main goals of PBL are to guide students to become experts in a field of study and to facilitate the acquisition and the application of knowledge. According to a model by Barrows (1996), there are six core characteristics of PBL: (1) student centred, (2) small groups under tutorial guidance, (3) the tutor as facilitator/guide, (4) starting with authentic problems, (5) problems as a tool to achieve knowledge and (6) acquisition of new information through self-directed learning. A seventh point was later added: students learn by analysing and solving representative problems. PBL students are asked to put their knowledge to use and be reflective and self-directed learners. Conventional instruction, in contrast, is marked by large group lectures and instructor-provided objectives and assignments (Albanese & Mitchell, 1993). However, PBL obviously means different things to different people, so its applications vary considerably. The range of meanings and connotations makes it difficult to come to a universal definition (see Gijbels, Dochy, van den Bossche, & Segers, 2005).

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[2] The research project “MedCap” is a 2-year project (November 2007 to November 2009) funded by Lifelong Learning Programme Leonardo da Vinci. It involves five partners in four countries (http://www.medcap.eu/partners.html).

7.4.1 Implementing a PBL-Based Curriculum for Medical Students

Implementation of a PBL-based curriculum requires increased staffing and greater access to learning resources. Selection and design of the scenarios to be used depend on clear definition of a core curriculum which is integrated with clinical elements. The success of PBL tutorials depends largely on the effort invested in writing and presenting and refining scenarios and on the performance of the tutor. Well-designed scenarios and suitable "trigger material" will prompt the students to formulate specific learning objectives which lie within the scope of the module. Each group (8–10 students) will appoint a "scribe" and a "chair" and, with the facilitation of a tutor, will apply itself to the problem presented. One widely used process follows the so-called Maastricht "seven jumps". These are: definition of terms and problems; "brainstorming"; review/restructuring of explanations; definition of learning objectives; private study; results shared and assessment.

7.4.2 Empirical Evidence

In addressing the efficacy of PBL within medical education, it is necessary to define the outcome of interest. The medical knowledge acquired by students who complete PBL-based and traditional curricula appears to be similar (although knowledge retention may be superior in the former). These curricula also do not differ in the resulting clinical performance measures of their graduates (Colliver, 2000). Perhaps the apparent lack of benefit in PBL-based curricula may be due to the selection of outcome measure applied. Lycke, Grottum, and Stromso (2006) demonstrated that students in a PBL-based programme practiced more self-regulated learning and made use of a broader range of resources than those in a traditional programme.

In a meta-analysis of 43 quasi-experimental empirical studies, Dochy, Segers, van den Bossche, and Gijbels (2003) addressed the main effects of PBL on knowledge and skills. They were also able to identify several moderators of these effects (type of assessment, for example). This analysis as well as earlier literature reviews (see Gijbels et al., 2005, for an overview of six systematic reviews on PBL) concludes there is a robust effect of PBL on skills, while results for knowledge are inconclusive, but tend to be negative. While Gijbels and colleagues (2005) did not limit their literature search to the domain of medical education, all of the 40 studies meeting the selection criteria (e.g. empirical studies, course or curriculum comparison) for their meta-analysis on the effects of PBL came from that domain except one study from the field of economics. In contrast to the fact that PBL has been widely adopted, claims about its effects seem to rely almost exclusively on literature in medical education.

7.4.3 PBL and the Role of Technology-Enhanced Learning

The logistic and organisational limitations to making PBL "work" in the real world may be addressed using technology as a vehicle, enabler or facilitator. Some of core characteristics of PBL present by Barrows (1996) are considered in turn:

Student centred. Students learn what they are ready to learn. The personalised learning environment (PLE) is an ICT resource which enables an individual to access learning tools or services. The personal elements (e.g. personal hosting, portfolio) are blended with formal shared or community elements so that the learner identifies his/her own learning profile and learning path.

Tutor/facilitator. The high-fidelity simulator centres used for training in medicine and healthcare tend to offer learning sessions to small groups facilitated by one or two experienced trainers. Each scenario will be designed to achieve well-defined objectives. The format usually entails a briefing (familiarisation), simulation and debriefing sessions.

Authentic problems. The authenticity of the simulated environment will depend on both the scenario design (by experts) and the degree of immersion achieved by the simulation. Although unproven, it is likely that both of these sets of factors determine the extent to which learning benefits are transferred into the clinical setting (Ahlberg et al., 2007).

Problems as a tool. The subject matter for simulated scenarios is frequently a "critical event" (Gaba et al., 1998). Benefits include the learning related to events which occur infrequently during an "apprenticeship" and the absence of risk to patients during the "learning by doing". The opportunities to address human factors, communication and "crew resource management" may be less obvious.

7.4.4 Collaborative Learning and PBL in Simulation-Based Learning

The socio-cognitive activities of collaborating individuals can initiate various cognitive and meta-cognitive processes, for example explaining a situation, asking thought-provoking questions, elaborating together, exchanging arguments in a discussion, resolving cognitive divergences or modelling cognitive strategies (see King, 2007). However, these activities usually do not emerge spontaneously from a collaborative learning situation. In fact, group losses are more often observed than group benefits (Hertel, 2000). With respect to collaborative learning this means that at least some of the learners might learn less in the collaborative situation than they would when learning on their own.

Empirical research from various domains has shown that so-called external collaboration scripts are a promising approach to compensate for the problems described above (King, 2007). In short, a collaboration script is a directive that distributes roles and activities among learners and can also include content-specific support for the completion of a task (for a more detailed description of the collaboration script approach see Chapter 10).

In a recent study, Zottmann, Dieckmann, Rall, Fischer, and Taraszow (2006) investigated the effects of a collaboration script in the observational learning phases of a full-scale simulator course with video-assisted debriefing in anaesthesia. Their aim was to foster the individual and collaborative learning processes of the participating students for more focused and active participation, as well as the individual learning outcome of the ability or skill of applying heuristics to cope with a medical crisis situation (see Rall & Gaba, 2005). While the intervention was rather short, the expected positive effect of the script was found with regard to the learning processes, suggesting that further research should be conducted on the implementation of collaboration scripts in medical training situations.

7.5 Problem Solving: A Case Study of Screen-Based and Web-Based Simulations Design

The problem-solving educational approach is slightly different than the previous one, taking much more account of the knowledge involved in the problem resolution process. It is also a less often adopted approach in medical education than problem-based learning.

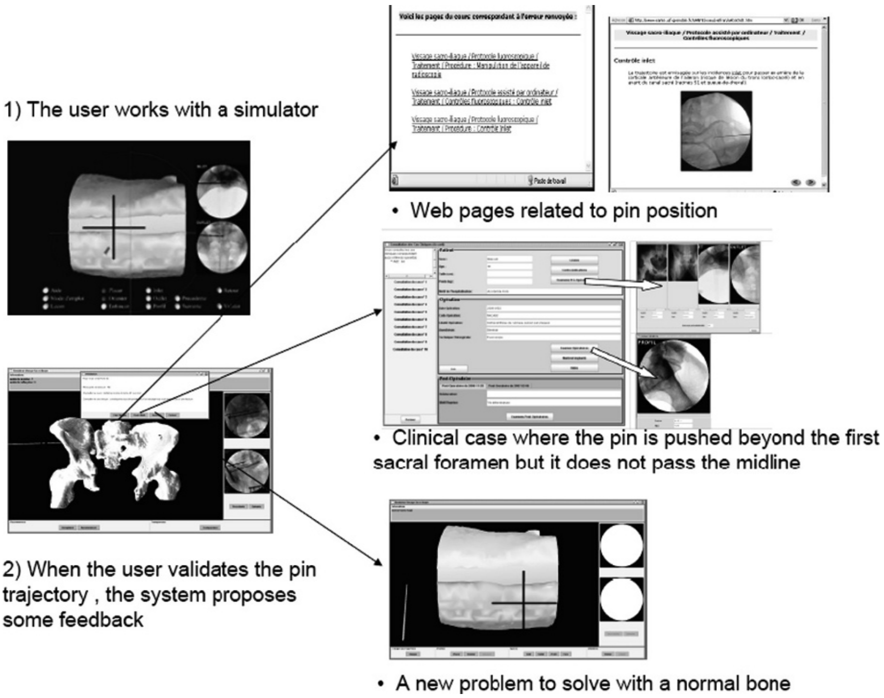
Within this educational approach the intent is thus to build problems which will allow the targeted knowledge to be developed by the subject during the problem-solving process. The authenticity of problems in this approach is not material but rather consists in an epistemic validity related to real work situations. It thus requires the design of training-oriented situations from work situations.

Relevant components of the situations are identified by analysis of the real activity, both from an expert point of view and from a training point of view. These components are then used to design problem situations that will be specific for the learning of this particular domain.

The “interaction” that we assume between the learner and the situation during the learning process implies that the situation itself can react, according to the learner’s actions (Brousseau 1997). This so-called feedback must be relevant for the learning perspective and the targeted knowledge. The feedback accompanies the subject in the learning process, by provoking reinforcements, destabilisations, hints and scaffolding, for example.

The TELEOS (Technology Enhanced Learning Environment for Orthopaedic Surgery) project assumes that a TEL device can produce relevant feedback for apprenticeship if it reacts according to an internal validation of the learner’s solution process.

The screen shots (Fig. 7.3) of the TELEOS system show how the simulator allows the trainee to position a pin in a pelvis, with appropriate visual feedback (X-rays during the process and transparency of tissues after the user’s confirmation). The aim is to train learners to place a pin which will be a guide for the placement of an



Voici les pages du cours correspondant à l'erreur renvoyée :

Vissage sacro-iliaque / Protocole fluoroscopique / Traitement / Procédure : Manipulation de l'appareil de radioscopie

Vissage sacro-iliaque / Protocole assisté par ordinateur / Traitement / Contrôles fluoroscopiques : Contrôle inlet

Vissage sacro-iliaque / Protocole fluoroscopique / Traitement / Procédure : Contrôle inlet

Vissage sacro-iliaque / Protocole assisté par ordinateur / Traitement / Contrôles fluoroscopiques

Contrôle inlet

Fig. 7.3 TELEOS feedback examples

ilio-sacral screw. This operation is percutaneous; this means that the validation of the pin's position is made through obtained X-rays.

The learning objectives of TELEOS are as follows: first, training in the correspondence between the two phenomenological domains of the 2D X-rays and the 3D body of the patient; second, learning the range of applicability of declarative pieces of knowledge according to the characteristics of the situation (age of the patient, type of lesion, etc.). TELEOS bases the system feedback on consistency checks of learner's actions rather than on a priori solutions. The user solves a problem using web simulation software. Tracks of the user's actions are analysed by the system in terms of their possible relationship to identified conceptions. A conception is an organised set of problems and pieces of knowledge. This cognitive diagnosis allows the system to make a didactic decision which determines the feedback to be given to the user.

As the declarative knowledge, gathered in an online course, indicates the validation criteria of a pin's trajectory for a general case, thanks to real situations cognitive analysis we have identified that each particular situation leads the surgeon to adapt this declarative knowledge. In some cases, the surgeon even seems to violate the prescription. We have called these adaptations of knowledge in a situation, "empirical knowledge", to emphasise their links to the reality of encountered situations. The different kinds of feedback proposed in TELEOS are calculated according to the cognitive diagnosis: as declarative knowledge is related to the redirection to a precise part of the online course, empirical knowledge is related to clinical cases to consult (playing the role of illustrations or counterexamples of the actions performed) and to the simulator (other problems are proposed, according to those previous and their treatments) (Luengo & Vadcard, 2005).

Let us take the example of a problem to solve, involving a patient who has a particularly dense bone (Fig. 7.3). The user's solution (the pin's trajectory) takes into account the particularities of this situation (in this case the pin can be stopped earlier than prescribed). As the trajectory is considered to be correct in this case, but only in this case, the system's learning objective will be to ensure that the domain of validity of this empirical knowledge is well known. It will thus calculate the appropriate set of feedback: the first feedback is related to the declarative knowledge, that is, the system proposes a set of Web pages related to the pin position; the second feedback is related to the empirical aspect, in that the system proposes another problem to be solved where in this case the bone is a normal one, not particularly dense; the third kind of feedback is an example or counter example, so that in this case the system proposes consulting a clinical case that shows the possible consequences of this solution applied to a normal bone (the pin will not be well enough anchored and has a good likelihood of getting out of the bone within a few days).

The challenge of this problem-solving environment is the adequacy of the system's reactions – feedback – with the user's knowledge. This adequacy relies on the calculation of a cognitive diagnosis based on the user's actions (Luengo & Vadcard, 2005).

7.6 Challenges

Modern simulation (3D, haptic, full scale, etc.) in medicine allows the performance of professional gestures of surgeons or doctors in a quite realistic environment. However, these environments have limited capacity to efficiently support training because of the difficulty of providing learners with the relevant feedback in the relevant form (Blavier et al., 2007; Issenberg et al., 1999).

This issue is related to a problem known from TEL research for two decades: the representation of expert knowledge (Clancey, 1983) or full-scale realistic simulations are not sufficient to provide reliable and efficient learning environments. The problem has specific complexity because the knowledge concerned is not explicit enough.

Hence, a critical issue in the design of TEL for medical training is the relationship between technology and training effectiveness. In the minimal invasive surgery case, we showed that new learning situations for novel technology are needed. In other cases, novel technology is necessary in order to improve the learning of particular skills, as we showed in the spinal anaesthesia case.

There are promising potential applications for simulation-assisted learning in the field of medical procedural skills because of its ability to provide hands-on learning in a risk-free, realistic environment. However, much of the research to date has focused on reproducing the physical and sensory environment and only thereafter evaluated it as an educational method. It is of course important to evaluate the simulator as an educational method, but designing simulators for training also implies designing educational activities and context. The argument here is thus that the principles listed below, including pedagogical questions, should be incorporated into the design process from the beginning:

- Learning outcomes, including core competencies, should be defined and be integral to the development and implementation of the learning systems.
- A multidisciplinary approach should be applied to the design and evaluation of technology, through an iterative design process.
- The applications of such systems should include not just training, but selection for specialty training, credentialing (and re-credentialing) and competency-based assessment.
- The role of human–human and human–machine interaction should be factored into the development of training programmes at the design stage.

The case studies we have presented show that sometimes the training device must be as realistic as possible, as in the spinal anaesthesia example, and at other times the device does not need to recreate this level of "realism", as in the case of the bench models for the minimal invasive surgery. We have also shown that on the one hand TEL environments need an appropriate learning situation (e.g. the collaboration script for PBL example), but in some cases, the learning situations must use specific tools (e.g. the orthopaedic surgery case).

For us the main challenge is to put forward computer tools, based on educational and cognitive science theories (Lillehaug & Lajoie, 1998), to re-think the TEL system in order to achieve adequate apprenticeship realism and to organise the feedback, which is linked to an interpretation of the user's actions in terms of knowledge used.

References

Aggarwal, R., & Darzi, A. (2006). Technical-skills training in the 21st century. *New England Journal of Medicine, 355*, 2695–2696.

Ahlberg, G., Enochsson, L., Gallagher, A. G., Hedman, L., Hogman, D., McClusky, D. A., et al. (2007). Proficiency-based virtual reality training significantly reduces the error rate for residents during their first 10 laparoscopic cholecystectomies, *American Journal of Surgery, 193*, 797–804.

Albanese, M., & Mitchell, S. (1993). Problem-based learning: A review of literature on its outcomes and implementation issues. *Academic Medicine, 68*, 52–81.

Barrows, H. S. (1996). Problem-based learning in medicine and beyond: A brief overview. *New Directions for Teaching and Learning, 68*, 3–12.

Blavier, A., Gaudissart, Q., Cadière, G. B., & Nyssen, A. S. (2007). Comparison of learning curves in classical and robotic laparoscopy according to the viewing condition. *American Journal of Surgery, 194*, 115–121.

Brousseau, G. (1997). *Theory of didactical situations: Didactiques des mathématiques 1970–1990* (N. Balacheff, M. Cooper, R. Sutherland & V. Warfield, Trans., Eds.). Dordrecht, The Netherlands: Kluwer.

Clancey, W. J. (1983). GUIDON. *Journal of Computer-Based Instruction, 10*, 8–14.

Colliver, J. A. (2000). Effectiveness of problem-based learning curricula: Research and theory. *Academic Medicine, 75*, 259–266.

Dochy, F., Segers, M., van den Bossche, P., & Gijbels, D. (2003). Effects of problem-based learning: A meta-analysis. *Learning and Instruction, 13*, 533–568.

Forbes, T. L., DeRose, G., Kribs, S. W., & Harris, K. A. (2004). Cumulative sum failure analysis of the learning curve with endovascular abdominal aortic aneurysm repair. *Journal of Vascular Surgery, 39*, 102–108.

Gaba, D. M., Howard, S. K., Flanagan, B., Smith, B. E., Fish, K. J., & Botney, R. (1998). Assessment of clinical performance during simulated crises using both technical and behavioral ratings. *Anesthesiology, 89*, 8–18.

Gallagher, A. G., & Satava, R. M. (2002). Virtual reality as a metric for the assessment of laparoscopic psychomotor skills: Learning curves and reliability measures. *Surgical Endoscopy, 16*, 1746–1752.

Gijbels, D., Dochy, F., van den Bossche, P., & Segers, M. (2005). Effects of problem-based learning: A meta-analysis from the angle of assessment. *Review of Educational Research, 75*, 27–61.

Hamilton, E. C., Scott, D. J., Fleming, J. B., Rege, R. V., Laycock, R., Bergen, P. C., et al. (2002). Comparison of video trainer and virtual reality training. *Surgical Endoscopy, 16*, 406–411.

Hertel, G. (2000). Motivation gains in groups: A brief review of the state of the art. *Zeitschrift für Sozialpsychologie, 31*, 169–175.

Issenberg, S. B., McGaghie, W. C., Hart, I. R., Mayer, J. W., Felner, J. M., Petrusa, E. R., et al. (1999). Simulation technology for health care professional skills training and assessment. *JAMA: Journal of the American Medical Association, 282*, 861–866.

King, A. (2007). Scripting collaborative learning processes: A cognitive perspective. In F. Fischer, I. Kollar, H. Mandl & J. M. Haake (Eds.), *Scripting computer supported communication of knowledge: Cognitive, computational and educational perspectives* (pp. 13–37). New York: Springer.

Kulcsár, Z, Aboulafia, A., Hall, T., & Shorten, G. (2008, June). Determinants of learning to perform spinal anaesthesia – a qualitative study. *European Journal of Anaesthesiology* EJA. *5*, 1–6.

Lajoie, S. P., & Azevedo, R. (2006). Teaching and learning in technology-rich environments. In P. Alexander & P. Winne (Eds.), *Handbook of Educational Psychology* (2nd edn.) (pp. 803–821). Mahwah, NJ: Erlbaum.

Lillehaug, S. I., & Lajoie, S. P. (1998). AI in medical education: Another grand challenge for medical informatics. *Journal of Artificial Intelligence in Medicine, 12*, 1–29.

Luengo, V., & Vadcard, L. (2005). Design of adaptive feedback in a web educational system. In P. Brusilovsky, R. Conejo & E. Millán (Eds.), *Adaptive systems for Web-based education: Tools and reusability* (pp. 9–17). Amsterdam: IOS Press.

Lycke, K. H., Grottum, P., & Stromso, H. I. (2006). Student learning strategies, mental models, and learning outcomes in problem-based and traditional curricula in medicine. *Medical Teacher, 28*, 717–722.

Marotta, J. J., & Goodale, M. A. (1998). The role of learned pictorial cues in the programming and control of grasping. *Experimental Brain Research, 121*, 465–470.

Rall, M., & Gaba, D. M. (2005). Human performance and patient safety. In R. D. Miller (Ed.), *Anaestesiology* (pp. 3021–3072). Baltimore, MD: Lippincott.

Romero, C., Ventura, S., Gibaja, E. L., Hervás, C., & Romero, F. (2006). Web-based adaptive training simulator system for cardiac life support. *Artificial Intelligence in Medicine, 38*, 67–78.

Ross, H. E., & Murray, D. J. (Eds.). (1996). *E. H. Weber on the Tactile Sense*. Hampshire, United Kingdom: Taylor & Francis.

Samurçay, R. (1995). Conceptual models for training. In J.-M. Hoc, P. C. Cacciabue & E. Hollnagel (Eds.), *Expertise and technology: Cognition and human-computer cooperation* (pp. 107–124). Hillsdale, NJ: Erlbaum.

Schön D. (1983). The reflective practitioner: how professionals think in action, New York: Basic Books.

Shaffer, D. W., Dawson, S. L., Meglan, D., Cotin, S., Ferrell, M., Norbash, A., et al. (2001). Design principles for the use of simulation as an aid in interventional cardiology training. *Minimally Invasive Therapy & Allied Technologies, 10*, 75–82.

Sidhu, R. S., Tompa, D., Jang, R., Grober, E. D., Johnston, K. W., Reznick, R. K., et al. (2004). Interpretation of three-dimensional structure from two-dimensional endovascular images: Implications for educators in vascular surgery. *Journal of Vascular Surgery, 39*, 1305–1311.

Stone, R., & McCloy, R. (2004). Ergonomics in medicine and surgery. *BMJ, 328*, 1115–1118.

Vadcard, L., & Luengo, V. (2005). Interdisciplinary approach for the design of a learning environment. In G. Richards (Ed.), *Proceedings of World Conference on E-Learning in Corporate, Government, Healthcare, and Higher Education 2005* (pp. 2461–2468). Chesapeake, VA: AACE.

Zottmann, J., Dieckmann, P., Rall, M., Fischer, F., & Taraszow, T. (2006, June). *Fostering simulation-based learning in medical education with collaboration scripts*. Paper presented at the 12th Annual Meeting of the Society in Europe for Simulation Applied to Medicine (SESAM), Porto, Portugal.